

STRUCTURAL AND STRATIGRAPHICAL CONTROL  
OF COPPER MINERALISATION AT MOUNT LYELL.

(With 19 Text Figures)

by

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## ABSTRACT

Copper ore at Mount Lyell occurs in quartz chlorite and quartz sericite schists derived from both Cambrian and Ordovician sediments. Mineralisation is centred at points of intersection of the longitudinal, deep-seated Lyell Shear, and cross-cutting E-W and NW faults. Within the mine area the Lyell Shear is expressed at and near the surface as a discontinuous, overturned, asymmetrical syncline with richer ore in the axial and the flat east limb positions, and with lower grade ore in the steep west limb.

As yet by no means all of the flat east limb positions have been prospected, so that the field holds an exploration potential of more than ordinary interest.

## INTRODUCTION

The interpretation of structural control at Mount Lyell is the result of four and a half years of geological investigation. This represents the longest period of geological examination ever undertaken at Mount Lyell and it is felt that the conclusions herein made, would never have been drawn if regional mapping of the field had not been undertaken. This idea will be developed later in the thesis.

The Mount Lyell Copper Mines are located on the West Coast of Tasmania, sixteen miles inland from the Southern Ocean (Fig. 1). They are in an exposed position on the western side of the West Coast Range between 1400 and 1800 feet above sea-level. The mining township of Queenstown is about one mile to the south-west, in the Queen River Valley about 500 feet above sea-level. Cold winds sweep in from the sea and rain falls in every month of the year, the average annual rainfall at Queenstown being 100 inches and at the mines 119 inches.

The mines have produced a total of 40,000,000 tons of ore containing 574,000 tons of copper, 18,000,000 ounces of silver and

680,000 ounces of gold. Nine separate mines have contributed to this total, of which North Lyell has yielded 43%, West Lyell 33%, and the Mt. Lyell Mine 12% of the copper. Reserves are published as 45,000,000 tons of 0.73% Cu.

Mining at present is confined to the West Lyell Open Cut and involves the removal of the largest combined tonnage of ore and waste of any metalliferous mine in Australia, over 4 million tons of material being mined annually, ore production is 2 million tons per annum. The ore now mined contains approximately 0.7% Cu., and 9.5% pyrites, with a small though significant amount of gold and silver. Published reserves are sufficient to prolong the life of the open cut mine for a little over 20 years, making a total of about 85 years for the field. In addition there are substantial underground ore reserves but all the mines are closed at the present time. The copper ore is concentrated by flotation, reduced by smelting, and electrolytically refined to pure cathode copper in the Company's works at Queenstown.

The Mount Lyell Mining and Railway Company possesses its own railway system connecting the Reduction Works with the port of Strahan, where it joins the Tasmanian railway system. It also possesses a hydro-electric system powered from Lake Margaret, 6 miles north of Queenstown, where rainfall is 146 inches per annum.

#### GENERAL HISTORY

The Mount Lyell Mine was discovered in 1883 by prospectors who were searching for gold. After being worked unsuccessfully for gold, the Mt. Lyell Mine was developed as a copper mine and by 1891 several other mines had been discovered in the vicinity. A bonanza of copper and silver enabled the Mt. Lyell Company to establish a railway and smelters, and in 1896 copper matte was produced by direct pyritic smelting of the Mt. Lyell ore. Production has been continuous ever since.

The rich North Lyell orebody discovered in 1897 encouraged the North Lyell Company to build its own railway to Kelly Basin and

its smelters at Crotty, but treatment methods failed and the future of the field became assured only when the two major companies amalgamated in 1903.

Scores of leases were pegged out around Mount Lyell but few payable orebodies were found and only four early companies worked at a profit. Gradually leases were abandoned or sold to the Mount Lyell Company who now hold the entire field in one consolidated lease.

#### PREVIOUS GEOLOGICAL WORK

The first geological report on the Mt. Lyell mining field was published in 1886 by Thureau (22). This was followed by a number of small reports by Alexander; Daly; Grayson; Haber; Johnston; Lawson; Montgomery; Muir; Officer, Balfour and Hogg; Peters; Power; Stewart; and Twelvetrees. Gregory made the first comprehensive worthwhile report in 1904 and this was published in 1905 (8); he recognised the ore control as structural and that the orebodies occurred close to a contact between conglomerates and schists, the latter being derived from volcanics and intrusives.

Hills (9) presented a somewhat confused picture of faulting and thrusting and he regarded the schists (known as the Lyell Schists) as derived from pyroclastic rocks underlying the conglomerates.

Nye, Blake and Henderson (12) thought the schists were altered igneous rocks that intruded the conglomerate. They were the first to map the zones of low grade mineralisation.

Edwards (6) made an important contribution to the knowledge of the mineral composition of the Mount Lyell copper ores.

Conolly (5) was the first geologist to map and elucidate the structure as a result of detailed mapping and his work paved the way for a lengthy exploration campaign by diamond drilling. He followed the work of Nye et alia in regarding the Lyell Schists as intrusives.

Alexander (1) presented a general summary of the mine geology, largely based on Conolly's work.

Carey (4) elucidated the regional setting of the Lyell ore deposits and recognised that the host rocks were sediments and volcanics deposited in narrow geosynclinal basins flanking a Precambrian block; he regarded all copper mineralisation as controlled by the Lyell Shear.

This general picture was amplified by Bradley (3) as a result of regional reconnaissance mapping and he suggested that the Lyell Shear controlled regional metamorphism and sedimentation besides mineralisation.

## REGIONAL GEOLOGY

### Tectonics

It is impossible to discuss stratigraphy or structure at Lyell without thinking in terms of the tectonic history of the area. Carey (4) introduced the concepts of tectonic control which have been used in the current geological work at Mount Lyell. He envisaged a central, resistant Precambrian (Tyennan) massif which has had a profound influence on sedimentation and the development of structure on the West Coast of Tasmania.

Early in the Cambrian a eugeosynclinal environment developed west of the Tyennan massif. Moulded against and parallelling this same massif, meridional zones of folding and weakness developed and Palaeozoic sediments were crumpled against the massif by forces operating from the south-west. The general tendency was for movement in the sedimentary prism of west side up and north.

The principal structural ore control in the Queenstown district, the Lyell Shear, seems to have been active at intervals throughout the whole of the Palaeozoic. Other structural elements are related to the forces operating from the south west against the resistant Tyennan massif.



TABLE 1

<u>RECENT</u>	river gravels
<u>PLEISTOCENE</u>	moraines
<u>TERTIARY</u>	river gravels
<u>PERMIAN</u>	tillite

- - TABBERABBERAN OROGENY - -

<u>SILURO-DEVONIAN</u>	Eldon Group:	Sandstone, quartzites and shales
<u>ORDOVICIAN</u>	June Group:	Gordon Limestone
		Owen Conglomerate
		Jukes Conglomerate

- - TYENNAN OROGENY - JUKESIAN MOVEMENT - -

<u>CAMBRIAN</u>	Dundas Group:	Greywackes, pyroclastics, lavas and siltstones
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- - TYENNAN OROGENY - STICHTAN MOVEMENT - -

<u>PRECAMBRIAN</u>	Quartz mica schists, quartzites etc.
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### Stratigraphy

The regional stratigraphy has been mapped by Solomon (20). His table of the stratigraphical succession is given in Table 1 and his generalised geological map of the Queenstown area in Fig. 2.

Early in the Cambrian a eugeosynclinal environment developed, flanking the west of the Tyennan massif. It received little sedimentation from the massif but volcanic activity and local earth movements resulted in the deposition of at least 5000 feet of greywackes, lavas and pyroclastics which form the Dundas Group (Carey (4)).

In the Ordovician, conditions of sedimentation had profoundly altered, and sediments were received mainly from the east from the Precambrian massif. When the deposition of the Owen Conglomerate commenced in the early Ordovician or late Cambrian, small ridges and islands remained elevated, and in the Queenstown area, portions of one ridge, namely the Dundas Ridge, were only covered in the final phases of Owen Conglomerate deposition.

The Owen Conglomerate is almost entirely siliceous and is composed of quartz pebble conglomerates or sandstones. In contrast to the Dundas Group there is generally a marked degree of sorting and evidence of prolonged wave action along an old shore line. A thickness of between 2500 and 3000 feet of siliceous conglomerates was accumulated.

In the field mapping, some evidence was found for an interfingering of Dundas type sedimentation with that of Owen Conglomerate. This evidence was found particularly where the base of the Lower Owen Conglomerate shows signs of rapid thinning (Fig. 13) and again at a certain horizon in the Middle Owen.

The important stratigraphical control for ore at Mount Lyell is the sharp contrast between the relatively incompetent, more basic greywacke conglomerate and volcanic facies of the Dundas

sedimentation, and the highly competent, hard, siliceous, conglomerate facies of the Owen Conglomerate. The less competent facies lent itself readily to shearing, alteration, and mineralisation, whilst the competent facies developed beautifully preserved fold structures and only sheared or brecciated locally where movement was most intense.

### Structure

The structures controlling ore deposition were developed during the Tabberabberan orogeny, of Mid-Devonian age. The tectonic forces, which had controlled sedimentation in the Lower Palaeozoic, intensified during Tabberabberan orogeny, and there is evidence of overlapping, if not contemporaneous development of more than one principal structural element. Hydrothermal alteration and metallisation followed as a later phase of the Tabberabberan orogeny; the most intense hydrothermal alteration and the emplacement of orebodies was entirely influenced by the Devonian structures.

In his regional report Solomon (20) sets out the principal regional structural elements as follows (Fig. 3).

- (a) The N-S West Coast Range anticlinorium, the King Sophia synclinorium, and related secondary folds.
- (b) The N-S Lyell Shear and the Toft-Crotty structure.
- (c) The NW fault-folds and NW schistosity.
- (d) The Linda Disturbance.

He describes the West Coast Range anticlinorium with its flanking synclinoria as the major structure of the area, upon which all other structures are superimposed. It has a N-S trend with the axis passing to the east of Queenstown and it is markedly asymmetrical, the secondary drag folds showing vertical or overturned and often severely attenuated eastern limbs. It expresses the squeezing of the geosynclinal sediments against the rigid craton by east directed forces.

The Lyell Shear is an important N-S feature parallelling the Range from Comstock to South Darwin. It is associated with local overturning and attenuation, with granitisation and metallisation. Its points of conflict with cross-cutting structure are foci for the deposition of sulphides. From Comstock to Mt. Huxley it flanks the western edge of the Range, but from Huxley to South Darwin it hugs the eastern side; its trend is best indicated by the line of mineral occurrence along its length, for, with few exceptions, these lie on a narrow N - S belt from Comstock to Prince Darwin (Fig. 4).

Movement on the Shear has been west-side-up and north, combining vertical and transcurrent movement. It has been mapped as an intermittent zone of overturning and faulting, varying in its surface expression and locally absent. This is due in part to offsetting of the structure by tear movement on NW faults and partly due to variation of surface expression induced by varying depths to bedrock, and changes in the physical properties of the overlying sediments; in depth it is probably a fault.

The NW faults are important structures which have a strong influence on ore occurrence. They are essentially asymmetrical, NE facing folds in which the steep limb has been faulted out; hence the term fault-folds. They throw down to the north and swing in strike from WNW to NNW. They are cognate with the Lyell Shear and interplay with the latter structure to produce locally unique developments. In places the Lyell Shear drags the NW folds to N - S trend (by west side north movement), elsewhere the NW faults appear to displace the Shear. They reach their greatest development in the Lyell area, where they show certain anomalous features; the faults swing to WNW trend and near Mt. Lyell and Comstock they face and throw down to the south. This produces a crude WNW rift valley structure (see Fig. 5) in which the rocks are more intensely plicated and faulted than elsewhere; this structural pattern reflects the influence of the Linda Disturbance, an E - W or WNW zone of faulting which may be traced for many miles east and west of the range. All the large, rich copper orebodies of the Lyell area fall within the boundaries of this cross-cutting feature.

TABLE 2

SEDIMENTARY ROCKS

Pleistocene : Moraines

Ordovician : Gordon Limestone : black shale and some Limestone

Owen Conglomerate

Upper Owen : Pioneer Beds : grey sandstone

variable sandstone  
and conglomerate

Chromite quartzite  
and conglomerate

- - Haulage Unconformity - -

Chocolate Sandstone with hematite  
beds

Middle Owen : Yellow conglomerates

Red sandstone

or alternating conglomerate and  
sandstone

Lower Owen : Coarse pebble conglomerate with  
a red sandstone horizon.

METAMORPHIC ROCKS

These are variable quartz sericite and quartz chlorite schists, often showing relict sedimentary structures, and red ferruginous clays, derived from the Gordon Limestone. The schists, known locally as the Lyell Schists, outcrop over the western slope of the Lyell-Owen divide and abut against the sedimentary rocks more or less along the divide. The schists represent part of the Owen Conglomerate, the Jukes Conglomerate and part of the Dundas beds but considerable difficulty is experienced in ascertaining the original nature of much of the schist series.

The NW faults tend to occur mainly in the competent, massive Owen Conglomerates, for in the softer, more yielding Dundas rocks, pressure is relieved by development of schistosity with NW trend.

#### GEOLOGY OF THE LYELL MINES

The rocks outcropping in the immediate vicinity of the Lyell mines are summarised in Table 2; the geology of the Lyell district is shown in Fig. 6, (after Solomon) while more detailed plans of the topography and geology of the mine area are shown in Figs. 7 and 8 respectively (after Wade and Solomon). Many of the rock-unit terms have only local significance and are adopted merely to assist in field mapping and description. Fig. 10 (after Wade and Solomon) shows a generalised plan of the Lyell orebodies.

#### Sedimentary Rocks

##### Owen Conglomerates

The Lower Owen Conglomerates are typically coarse siliceous conglomerates, with pebble size averaging very large or greater. The pebbles are mainly quartz, quartzite, chert, and quartz schist and show a high degree of rounding while the matrix is grey or pink quartz. Locally, boulders of quartzite and quartz reach a diameter of 2 feet, and the conglomerates are massive and poorly bedded. In the North Lyell Tunnel, 4900 feet from the portal, a pink sandstone several feet thick occurs in typical Lower Owen Conglomerate and this horizon appears to have been encountered in deep bores of this vicinity. Conolly (5) regarded this as a potential ore horizon but the recent work has failed to substantiate this view.

The Middle Owen Beds are a variable series of large pebble conglomerates and red quartzites. Over Mts. Lyell and Owen, and on the Razorback ridge, a clear cut division into two units is possible; an upper grey-yellow conglomerate and a lower red quartzite, with individual thicknesses varying considerably. However, near

the Tharsis ridge, conglomerates and sandstones are interbedded, and near Comstock it is impossible to apply the two-fold sub-division. Fig. 9 (after Solomon) demonstrates the variability of the Owen formation.

The Middle Owen Conglomerate is a yellowish large-pebble quartz conglomerate with thin sandy beds; it grades upwards through finer conglomerates to the Chocolate Sandstone, but shows a sharp change at its base to red quartzite. On the Razorback ridge it is about 450 feet thick and contains coarser bands of unusual type. These are somewhat poorly sorted, lenticular, and composed not only of the usual rounded quartzose pebbles, but also of sub-angular fragments of pink sandstone and hematite, and a few conglomerate pebbles; this rock type is known locally as hematite conglomerate. The Middle Owen Conglomerate horizon is important as in it the most important orebodies occur (e.g. North Lyell and the Mt. Lyell Mine).

The underlying red quartzite is well exposed on Mts. Owen and Lyell and on the Razorback. It is blocky but very thinly bedded, and has the grain size of a coarse sand. It is more resistant to metamorphism than the conglomerate facies, probably due to its finer grain, and remnants of quartzite are often seen in the adjacent schist up to 600 feet from the contact. On the Tharsis ridge, the lower half of the Middle Owen beds are exposed but instead of the usual red quartzite, lenticular bands of coarse hematite conglomerate alternate with thin beds of red sandstone showing cross-bedding and current scouring. In some places the sandstone facies dominates, in others the beds are almost entirely conglomerate. These beds suggest unstable conditions of deposition, probably near a shore rich in ferruginous material. Further variation in the Middle Owen lithology is seen at Comstock; at Cape Horn the typical conglomerate and underlying sandstone are well developed, but passing towards Comstock this sub-division is lost and the Middle Owen beds thin out and almost disappear near the mine. Once again, the ore-body near the surface occurs along the strike of the upper Middle Owen. Near the Comstock open cut, unusually coarse conglomerates with a dark hematite matrix occur in the Middle Owen and similar but finer grained conglomerates may be seen at this horizon just north of Mt. Owen summit.

The Upper Owen Conglomerate is sub-divided in the Lyell area by the Haulage unconformity. Below this horizon is the Chocolate Sandstone, which lies conformably on the Middle Owen conglomerate. It has basal fine conglomerates which provide a transition from the Middle Owen to the Upper Owen. The sandstone is typically pink, thin-bedded, and quartzose, with local shale bands and hematite-rich beds; it is characterised by "balling-up" of sandstone layers by current disturbances and by closely packed jumbles of thin sandstone tubes lying on bedding planes. These are trace fossils and Professor Caster of the University of Cincinnati has suggested in conversation that they may represent the fossil excreta of worm colonies.

The hematite beds are generally less than 3 feet thick, and occur some 200 feet above the base of the Chocolate Sandstone. They are well exposed on Pioneer Spur, where two 3 feet beds, about 10 feet apart, are interbedded with normal pink sandstone. They show the trace fossils of the pink sandstone, but when examined by hand-lens, can be seen to be composed of discoidal elements averaging about 1 m.m. in diameter. Professor Caster, on being shown a typical specimen, said that it resembled the Clinton iron ore, which is known to be of organic origin; an assay of a representative sample indicated 40%  $\text{Fe}_2\text{O}_3$ . In places the hematite bands are associated with grey or yellowish sandstones, as if the iron in the latter had been removed and concentrated in the former. At a number of points, re-crystallisation of the iron-rich beds has produced a dense hematitic quartzite. This horizon can be traced from Gormanston to North Lyell and can be seen at Comstock, but on Mts. Lyell and Owen its place is taken by a variable series of hematitic shaley sandstones and thin bedded quartzites.

The Haulage unconformity marks an interruption to Owen sedimentation and reflects movements along the Lyell Shear. Older sediments were upturned and tightly folded along narrow N - S zones and the ensuing erosion locally removed much of the Chocolate Sandstone. As a result the succeeding Pioneer beds rest almost on Middle Owen



Conglomerate at a number of places. East of these zones of localised movement the Pioneer beds rest on Chocolate Sandstone with conformity.

The Pioneer beds rest on the erosional surface cut in Chocolate Sandstone. This is generally overlain by rose-pink conglomerate, grey sandstone, or basal breccia which is well exposed near North Lyell, and contains sub-angular fragments of hematite up to several inches in diameter, and pebbles of Chocolate Sandstone. The conglomerate and grey sandstone are characteristic beds which usually contain tiny chromite<sup>1</sup> grains, averaging  $\frac{1}{2}$  m.m. diameter and showing both rounded and sub-angular form. The chromite may well be derived from a serpentine mass newly exposed by the Haulage uplift, though there is no known serpentine in the locality.

#### Gordon Limestone

The youngest of the Palaeozoic rocks outcropping in the mine area is the Gordon Limestone. It is represented by blue-black shales and clay with local limestone lenses, and has been mapped mainly along the eastern side of the Lyell-Owen divide and east of the Crown Lyell quarry; it is well exposed in the creek beds near Linda. The red clays, often carrying native copper, that occur in the synclinal valleys adjacent to the Pioneer, Linda, and Gormanston Spurs are probably derived from Gordon Limestone by hydrothermal alteration.

#### Pleistocene

The Pleistocene is represented by glacial moraines consisting of coarse boulders and finer pebbles in a varved glacial clay. This glacial till blankets bed-rock near the Mt. Lyell Mine and Gormanston, and near Comstock. It consists of varved clays and boulder beds and occurs between 850 and 1500 feet above datum.<sup>2</sup> At its limits it is only a few feet thick but near Gormanston there may be over 100 feet at any one point. The moraines mark the limit of a distributary ice flow of the King Glacier, and the site of an

1. An analysis of the separated grains gave 56.1%  $\text{Cr}_2\text{O}_3$ .
2. 100 ft. below mean sea level at Strahan.

ice-dammed lake which overflowed at the Gormanston Gap. The ice did not continue beyond the Lyell-Owen divide, as evidenced by the complete lack of glacial deposits or physical features on the western flank of the range in this area. Again at Comstock the ice sheet did not extend very far west of the western end of Comstock Valley. A few hundred yards west of the Comstock Mines, glacial dolerite boulders occur at approximately 1700 feet above sea-level, suggesting that the Comstock ice was thicker than that in the Linda Valley and extended west of the Comstock Mine. Radiocarbon analysis of a specimen of wood in the Gormanston moraine indicates an age of  $26,480 \pm 800$  years, placing the glaciation in the Wisconsin stage (Gill (22)).

### Structure

The Lyell ores occur in rocks that exhibit considerable original lithological differences and variation in mode of formation, and reflect a high degree of Lower Palaeozoic tectonic instability. Minor localised movements culminated in the Devonian Tabberabberan Orogeny, during which the rocks were thrown into their present day attitudes.

Earlier movement phases appear to have been localised along the Lyell Shear, a major structure which has been the controlling factor in West Coast Range sedimentation, the movements generally resulting in west side up displacements. Often, however, the faulting was not simple movement on north south axes but was accompanied by displacement along east west lines and was expressed by folding rather than faulting.

The earliest movement phase that can be studied in detail in the Lyell area is that indicated by the Haulage unconformity and known as the Haulage Movement.

The Haulage unconformity indicates west side up movement on the Lyell Shear during the early Ordovician, accompanied by east-west displacements.

### Tabberabberan Structure

The conglomerates of the Lyell area exhibit complex folding and faulting on several well-defined lines. The chief structural elements identified by detailed mapping are those also revealed in the regional survey and which have already been briefly described.

The dominating influences are west-side-north and up movement on the Lyell Shear, and vertical transcurrent NW-- WNW faulting controlled by the Linda Disturbance; these features are superimposed on the N - S West Coast Range anticlinorium.

Lyell Shear displacement at depth, is expressed at the surface as upturning and overfolding on N - S lines, echeloned along the Lyell-Owen divide. The resulting structures may be studied in Owen Conglomerate at the western ends of the spurs that finger out towards Linda from the divide (see Fig. 7). The NW striking folds of these spurs are sharply upturned to N - S trend at their western ends, the upturned limb often overturning and exhibiting tight, small scale folding. Such features are well exposed on the Whaleback and in the Blow open-cut; surface exposures in the latter locality show only uniformly west-dipping beds, but in section on the south-east wall of the cut, tight isoclinal folding is discernible. (See photo, page 30).

The nature of the Shear movement is indicated by the sections in Figs. 11, 12 and 17; the axis of upturning generally dips west at between  $30^{\circ}$  and  $50^{\circ}$ . Conolly (5) terms this structure the Razorback fold. It is noticed that the point of upturn generally coincides with the thinning of the Owen Conglomerate.

Some difficulty is experienced in following out the axis of the upturning on the surface. It is clear to see at many points, particularly on the Whaleback, Linda and Pioneer Spurs but in other areas it is apparently absent, and no continuous line can be traced along the divide. This picture of intermittent upturn is typical of the Lyell Shear and like features have been mapped on a regional scale. It appears that the line of upturn is interfered with by east-west to north-west striking structures (generally faults) which

were active either at the same time as the Lyell Shear or slightly after it. Conolly (5) considered the two elements combined and could not be separated in time; he linked the upturn at the Mt. Lyell Mine and at North Lyell by a straight line striking N20°W, and described intersecting folds striking N20°W, and N60°W. Actually the upturn strikes longitudinally but outcrops intermittently and on echelon, stepping north side west.

The general picture is obscured near the Mt. Lyell Mine by the Razorback fault - this slices across the upturn (see Fig. 8) and repeats the structure as shown by the section in Fig. 11. Other faults of near longitudinal trend complicate the upturning and overfolding associated with Lyell Shear movement.

NW and WNW faulting and folding combine with the Lyell Shear to form the basis of the structure at Lyell. As already described in the regional picture, NW-striking high-angle reverse faults form a crude rift structure centred on the Linda Valley, as a result of the influence of the cross-cutting Linda Disturbance. With east-pitching folds at Lyell and west-pitching folds at the eastern end of the Linda Valley a small basin is formed which Hills (9) described as the "Linda saucer".

The Lyell-Owen divide lies on the western rim of this basin and shows north and south facing asymmetrical folds which plunge east. These folds are well exposed on the Pioneer, Linda, and Gormenston Spurs, the ridges coinciding with anticlines and the intervening valleys marking the synclines. In this area they trend almost E - W, with relatively flat south limbs and steep, usually faulted, north limbs; together they impart a wave-like form to the conglomerates. These north-facing folds are met by south-facing features along 2000S, making the zone between 2000S (the Whaleback fault) and 3200S (the Pioneer fault) the lowest point of the rift structure along the divide (Fig. 5). Passing north and south from this area, the conglomerate is gradually stepped up by folding and minor E - W faulting until the Owen Spur and North Lyell faults are reached. These are major faults facing each other across the Linda Valley and marking zones of considerable crushing and vertical throw. North

and south of these again the structure is repeated with faults on Mt. Owen throwing down to the north and faults in the Comstock Valley throwing down to the south.

The points of intersection of these NW and E - W faults with the Razorback fold are foci for ore deposition. It is clear from Fig. 8 that the location of the major orebodies is closely related to these faults and also to the line of the Lyell Shear upturn and it may be concluded that local brecciation and crumpling caused by the intersection of these two structural elements has produced suitable host rock for ore deposition.

It has already been suggested that it is uncertain whether the N-S and E-W structures are contemporaneous or not, but in a few cases it seems obvious that the transverse structures have sliced across and displaced the line of longitudinal upturn. This is particularly marked in the case of the North Lyell fault, which offsets the Shear some 3500 ft. to the west on its northern side, the axis of upturn at North Lyell is displaced to the west of Cape Horn and then swings back to Comstock in a gentle curve (see Fig. 6). The lateral displacement can be explained by vertical movement only (see Conolly (5)), but in a similar case at South Owen, a few miles to the south, wrench movement has undoubtedly taken place and it seems probable that the North Lyell displacement is of similar type. As can be seen from the section in Fig. 12 the fault also shows considerable vertical throw and the problem is whether the two types of movement took place in one stage of oblique slip, breaking across the Lyell Shear; or whether there was a phase of vertical movement during the NW and N - S folding, followed by a later phase of sinistral wrench movement after Lyell Shear upturning. Similar remarks apply to several of the E - W faults that appear to displace the N - S upturning in a direction north side west.

The North Lyell and Owen Spur faults are marked by wide zones of intense crumpling and brecciation where they intersect the Shear, and it is significant that the two richest orebodies, North Lyell and the Mt. Lyell Mine, are closely connected with these complementary crush zones.

Comstock is associated with another major transverse fault (the Comstock Fault) but the opposite number on Mt. Owen has only minor mineralisation along its length.

Several lines of evidence suggest faulting has taken place along the contact between schists and conglomerate in a number of places. The movement appears to vary, and involves both horizontal and vertical displacement, resulting in further complications to the structural picture. The contact seen in the walls of the Mt. Lyell Mine open-cut may be cited as an example of contact faulting.

#### Stratigraphic and Structural Control

In his regional report Solomon has shown that during Owen Conglomerate deposition, islands of Dundas rocks along the Shear zone remained elevated and shed greywacke type detritus around their margins. These islands were slowly buried with the Owen beds gradually overstepping greywacke detritus until they rested on original Dundas surface. Fig. 13 (after Solomon) shows the effect of upturning such a feature, and he applies it to the West Lyell schist-conglomerate contact. Similar conditions of sedimentation along the unstable, narrow Shear zone occur in the Lyell mine area and Solomon and the author measured a rapid thinning of the Owen Conglomerate from east to west across the mine area which explains why the conglomerates appear to pass directly along strike into schists, the schists representing the incompetent sheared Jukes formation or beds of the Dundas group.

It is also possible to explain in a general manner Conolly's "silling" of schist at North Lyell, shown in Fig. 11 (a); localised and sudden uplift along the Lyell Shear during Owen deposition might well have resulted in a limited incursion of Dundas detritus in place of siliceous conglomerate, and the softer material later being sheared to give the impression of an intrusion of schist.

Thus the main features of the conglomerate-schist junction may be explained by facies variations along strike and this alone represents a major breakaway from Conolly's idea of intrusion and Bradley's theory of wholesale metasomatic replacement of the Owen Conglomerate beds.

However, when the contact is examined in detail, several anomalies appear that can only be satisfactorily explained by assuming some structural weakening leading to chemical alteration of the Owen Conglomerate. The more important lines of evidence leading to this conclusion are as follows :

At many points along the contact there is an insensible gradation from sandstone and/or conglomerate through sheared material to schist, and the exposures leave a distinct impression that the sediment is being converted to schist.

On the Tharsis Ridge (see Fig. 8), a prominent E-W fault shows a horizontal slip of almost 200 ft. in the Owen sediments, yet the contact of schist and conglomerate on either side of the Ridge shows no displacement whatever. The only reasonable explanation for this feature is that the conglomerates have been partly replaced at some stage after faulting took place. Again, at the southern end of the Tharsis Ridge, the Consols fault coincides with a break-through across the strike of the conglomerates that is unlikely to be related entirely to facies changes.

Particularly near the King Lyell clay workings, the sandstones immediately underlying the hydrothermally altered Gordon shales are kaolinised or converted to quartz sericite schists; this is another feature suggesting hydrothermal alteration of siliceous material, in a NNW fault crush zone.

The extent to which the Owen Conglomerate has been transformed is uncertain but it is undoubtedly restricted. Possible the schisting is confined to a narrow contact zone where high stress conditions prevailed due to frictional drag between incompetent and competent materials.

At the recent symposium on the Lyell Schists, many objections, on chemical grounds, were raised against the suggestion that the Owen beds had been altered, yet transformation of quartz to sericite is mentioned by Schwartz (17), and Leedal (10) describes replacement of quartz by albite in the Cluanie igneous intrusion. Again, feldspathisation of sandstones has been described from many parts of the world.

The problem of alteration of siliceous sediments is further discussed under the heading Lyell Schists on page 40.

En Echelon Structure (With Special Reference to West Lyell)

Formerly it had been realised that certain groups of ore-bodies at Lyell were arranged roughly en echelon. In particular an en echelon arrangement of the Lyell Comstock oreshoots was clearly recognised. Nye (12) mapped a broad scale, en echelon pattern of large zones of pyritic mineralisation, and Conolly in a Company Report in 1949, adopted Nye's broad en echelon arrangement to plan drilling prospects at the intersection of NW striking zones of mineralisation and a supposed NE alignment of groups of mineralised zones.

The control for individual ore shoots at West Lyell, however, was not very well understood. Since most of the Company's ore reserves were known to be in the West Lyell area, particular attention was paid by the writer to control of mineralisation in this ground. He was faced with the problem that here there was a major occurrence of some half million tons of copper, contained in a block roughly 3000 feet in length, upwards of 1000 feet in width and economically workable to a depth of 800 feet below outcrop. Yet there was no clear general picture of ore control, no firm outline of orebodies, except in the case of the Royal Tharsis and the West Lyell No. 1 (Honeypot), and possibly the Prince Lyell, and finally no idea of what would become of these orebodies at depth.

Several avenues of approach were followed concurrently in the field and in the office - the climate being admirably suited for such a division of labour. At first very little progress was made in an attempt to map the somewhat confused and variable schist rock types, for both host and wall rock schists have nothing in particular to distinguish them, whether barren, low grade or relatively rich in copper. Later, however, when relict sedimentary structures began to show up, as the author "got the feel" of the vague



sedimentary remnants in the schists, this self-same variability (specially when examined in thin sections, or subjected to chemical analysis) branded the schists as being derived from volcanic and greywacke facies, rapidly altering along strike and alternating in succession, and belonging to the Dundas group beds. Mapping of the relict sedimentary structures on weathered outcrops on the south-eastern and southern ends of the West Lyell Open Cut, though far from presenting a concise structural picture, gave sufficient evidence to indicate that the upturn axis had been displaced westwards some 1200 feet by the steep Razorback fault (Fig. 12) and that the beds, prior to schisting, had been in the vertical limb of the fold. This was the first key to an understanding of ore control at West Lyell. Instead of West Lyell ore being away out west of the main zone of mineralisation, structurally and stratigraphically in "No Man's Land", it was seen to be controlled by the vital overturned Razorback fold. Moreover the stratigraphic succession could be interpolated on E-W sections. This interpretation has since been confirmed by diamond drilling, where, west of the Razorback fault, a drill hole passed from Middle Owen into Lower Owen Conglomerate at the anticipated depth.

The field mapping immediately revealed a pattern of schistosity clearly related to the Tabberabberan structures. The schistosity aligns itself parallel to the NW fold-fault system and to the E-W Linda Disturbance described in the regional and mine area structural discussions. The prevailing direction of schistosity is north-westerly, but the E-W direction is particularly noticeable in and around the Honeypot, on the south end of the Prince Lyell and on the north end of the Tharsis Ridge. In all cases this E-W attitude of schistosity occurs where strong E-W faults, visible at surface in the conglomerates to the east, can be projected westwards a few hundred feet along strike. It is recalled here that in the discussion of regional structure it was remarked that the NW faults tend to occur mainly in the competent, massive Owen Conglomerates, for in the softer, more yielding Dundas rocks, pressure is relieved

by development of schistosity with north-west trend. Schistosity aligned in an E-W direction characteristically shows a rodding effect undoubtedly developed by transcurrent movement along the E-W faults.

Concurrently in the office a mathematical analysis was made of tens of thousands of assay results from samples taken in the mining of the West Lyell Open Cut, and of assays from some 360,000 feet of blast-hole churn drilling and of 75,000 feet of diamond drilling. It was found possible to accurately grade-contour the West Lyell area at each bench level of the open cut and less accurately, below the mined out area of the open cut, at 50-ft. vertical intervals. The contouring showed up six major orebodies (Fig. 14), the three principal ones being the Royal Tharsis, the Honeygot (West Lyell No. 1) and the Prince Lyell, with the Prince Lyell as the largest. It is obvious from the plan view (Fig. 14) and the cross-sectional view (Fig. 15) and the longitudinal view (Fig. 16) that the group of ore-shoots is arranged en echelon. Each orebody has within it some narrow low grade zones, strung out along schistosity, and each orebody also has a halo of low grade material, surrounded again by pyritic schist carrying about 0.1% Cu. The pattern is typical of low grade disseminated ore, with impregnation of chalcopyrite starting at multiple points or foci in planes of weakness (in this case, planes of schistosity) and spreading out until many centres of deposition coalesce (Figs. 18 and 19). The mechanism is described by Bateman (2) in his discussion of hydrothermal processes.

Referring again to Fig. 14, it will be seen that the West Lyell orebodies, as outlined by grade-contouring, not only show a general en echelon arrangement, as a group, but individual orebodies clearly take up the two attitudes of schistosity described above (Fig. 8). The Royal Tharsis, West Lyell No. 3, and the Prince Lyell are elongated along the north-west schistosity direction, but West Lyell No. 1 shows a marked swing to an E-W direction, the schistosity here being in two well developed directions, one, the normal north-west one, the other parallel to, and no doubt associated with, the E-W Pioneer fault.

When it had been established that the West Lyell mineralisation was, as elsewhere at Lyell, mainly controlled by the N-S overturned fold; that the orebodies were in sheared Dundas type sediments (volcanics and greywacke conglomerates) in the steeply upturned west limb position; and that individual ore-shoots were arranged en echelon, in the attitude of schistosity, it was then necessary to examine their pitch and plunge in order to plan deep drilling. (The plunge is defined as the angle between the long axis of the ore lens and its horizontal projection, after McKinstry (11)). As the orebodies have irregular outlines, and ragged ends in plan projection, their centres of gravity were determined experimentally by tracing off successive levels onto cardboard, cutting them out and suspending them from several points successively in a vertical plane. It was found that in general, for the West Lyell group of mines, the pitch of the centre of gravity is vertical and the plunge steep to the west.

An obvious en echelon arrangement is, therefore, well established for the West Lyell group of orebodies as well as for the Lyell Comstock group (Fig. 17) and for the large zones of pyritic mineralisation mapped by Nye.

There is evidence of a second echelon to the Crown Lyell orebody in the No. 4 to No. 6 levels of the Crown Lyell Shaft. In all these cases, as one orebody reaches the underlying schist-conglomerate contact another echelon becomes the main ore channel. The interpretation of this is that the schistosity becomes more highly developed near the resistant conglomerate mass, and as the conglomerate contact dips to the south-west, so do successive ore echelons appear, at depth, towards the south-west.

#### Interpretation of Stratigraphy and Structure

(As applied to ore search)

#### Application at West Lyell

From a study of the available data, it became apparent that two prospect targets were presented at West Lyell. One was concerned with the downward extension of the en echelon group of orebodies, in the steep, upturned limb position. The second, and

by far the more important one, was concerned with the "roll under" or flat east limb position, at the base of the Owen Conglomerate.

For the first prospect, sufficient information on structural control had accumulated to design a drilling programme to test the downward extension of known West Lyell ore. Dip and strike, pitch and plunge had been determined and the en echelon pattern enabled drilling to be directed at the richer ore-shoots. Several drill holes designed from this information made satisfactory intersections on West Lyell No. 2 and West Lyell No. 3 orebodies. The inference that the Honeypot would fail at depth, as it approached the schist-conglomerate contact, was confirmed. A row of six diamond drill holes was designed to cut the downward extension of the Prince Lyell orebody. All six drill holes intersected slightly wider and richer ore than in the open cut benches above. Two extra holes drilled outside either anticipated end of the orebody failed to cut ore.

A new West Lyell drainage tunnel has since been driven, 700 feet below the open cut and this will provide drilling sites to follow the downward extension of the Prince Lyell orebody.

In the cross-section through the West Lyell orebodies (Fig. 15), the West Lyell No. 1 orebody can be seen to be petering out as it approaches the conglomerate. In the same section the eroded top of the Prince Lyell just outcropped. The pitch of the whole en echelon structure, therefore, appears to be flat to the south-west, so that individual orebodies are encountered at successively greater depths towards the south-west. This raises interest in the geophysical anomalies and the sporadic copper mineralisation outcropping in the Glen Lyell area immediately to the south-west of the West Lyell waste dumps.

The more important prospect will now be considered.

Drilling for the deep "roll under" prospect, i.e. the appropriate stratigraphical position in the flat east limb of the overturn fold axis, is by no means a new concept at Lyell. Conolly stressed the importance of seeking for, and the likelihood of finding richer ore in repetition positions at depth. The author is in complete agreement with Conolly that such a repetition

is very likely to occur, but Conolly anticipated that the repetition would occur at a sandstone horizon in the Lower Owen Conglomerate into which porphyry had silled and then been converted into schist, whereas the writer thinks the repetition is much more likely to occur in the schist derivatives of the Jukes Conglomerate and the Dundas Group beds, stratigraphically beneath the Lower Owen Conglomerate. In effect, this difference in interpretation does not deepen the target area very considerably. Conolly was unfortunate in that the block of ground in which he recommended his "test-case" hole happened to lie between the Whaleback and Pioneer faults (Fig. 5) described on page 14 herein as the lowest part of the rift structure. Because of technical drilling difficulties the drill hole failed to reach the bottom of the column of Owen Conglomerates. Conolly (5) would have liked to select the North Lyell area for a deep repetition target, but the doubt arose in his mind as to whether the Linda Basin would remain as extensive in depth. It was possible, he thought, that the Linda Basin would contract in depth to its West Lyell core. Again and again in his prospect thinking Conolly expresses the idea that West Lyell is located in the heart of the NW, mountain making structures. This agrees with the structural concept already elaborated in this thesis of a crude rift valley structure (Fig. 5); and West Lyell lies near the centre of this rift, along the strike of the E-W faults.

The writer selected the block of ground between the King Lyell and the Razorback faults (Fig. 5) to test the prospect zone beneath the Lower Owen Conglomerate. The same prospect zone may be seen to better advantage in Fig. 12, where also the West Lyell orebodies are shown associated with the westerly displaced upturn fold axis. The orebodies figured here are regarded as "spill-outs" of low grade chalcopyrite which have escaped from the stratigraphical and structural trap position beneath the Owen Conglomerate. The copper has collected in planes of schistosity in schists which were originally steeply upturned Dundas Group beds, with possibly some Jukes Conglomerate also originally present. The orebodies are the equivalents of the Crown Lyell and the shallower North Lyell ore-shoots.

It is significant that two of the six drill holes mentioned above made occasional short intersections of bornite, at depth, as the drill holes approached the nose of conglomerate shown on Fig. 12 near sea-level. For this is near the "roll-under" position and is the first bornite reported from West Lyell and bornite was the ore so typical of the rich North Lyell Mine.

The prospect zone selected for deep drilling beneath West Lyell has all the hall marks of favourable structural and stratigraphical ore control. It has the strong cross faulting of the Razorback and King Lyell faults, the displaced upturn fold axis, and finally it has the Lower Owen Conglomerate passing along strike, as it thins out, into schists derived from Dundas Group beds and possibly Jukes Conglomerate.

There is not much doubt that the block of ground between the King Lyell and Pioneer faults (Fig. 5) would be just as good a prospect. Both blocks have the "spill out" ore of the operating West Lyell mines as an additional lure to deep drilling.

In the final count, initial drilling was designed and recommended at co-ordinate 4000 S (Fig. 8) to make use of the new West Lyell tunnel for a drilling site. The drill hole was designed first to thread the downward extension of the Prince Lyell echelon and then to pass on to the deep prospect zone beneath the Lower Owen in the vicinity of the King Lyell and Razorback faults.

#### General Application

Should the flat east limb position be found to carry copper orebodies at depth beneath West Lyell, then prospects in the same stratigraphical horizon and in similar structural positions beneath the old Blow Mine, the North Lyell Mine and the Lyell Comstock Mine would immediately "come alive". The interpretation of structural control, as developed in this thesis, is one which involves a repetition at depth (1700 to 2000 feet below outcrop) of the whole of the Mount Lyell group of orebodies, which stretch over a length of some  $2\frac{1}{2}$  miles.

#### Application of Geophysics

In the discussion on interpretation of structure and stratigraphy as applied to ore search, some reference must be made

to the application of geophysics at Lyell as a pre-drilling check on conclusions drawn. For structural and stratigraphic reasons, four areas were selected by the author for geophysical investigation by the Bureau of Mineral Resources.

#### The Glen Lyell Area

Rather weak copper mineralisation occurs at Glen Lyell at surface, and the en echelon arrangement of the West Lyell group of orebodies pointed to the Glen Lyell as the outcrop of the very top of the next echelon. The mineralisation here, as at West Lyell is in the steep upturn limb at the base of the Owen Conglomerate. Accordingly the Bureau of Mineral Resources was asked to carry out geophysical work in the Glen Lyell area south-westwards from the West Lyell Open Cut. Their work was extended some 2000 feet to the south-west across the Queenstown-Gormanston road. Because of the West Lyell dumps and the H.E.C. high voltage power line, the first 700 feet, the important zone for the next echelon orebody, could not be surveyed geophysically. However, the Bureau did outline the southern end of an anomaly passing in under the dump, and other anomalies, arranged en echelon, towards the south-west. One drill hole was bored into the first of these, but only rich pyrite and low grade copper were intersected. However, further drilling is required in this area.

#### The Great Lyell Area

Immediately to the south of the Glen Lyell area just described, another area was selected for geophysical attention for structural and stratigraphical reasons. This is the Duke and Great Lyell area (Fig. 4).

At Great Lyell there is only a small area of outcrop, but some good copper values are quoted in old reports from a small open cut and a shaft 170 feet in depth. The surrounding area is covered with glacial outwash. The workings are in schist on the north-west end of a long narrow ridge of Lower Owen Conglomerate. Structures mapped on this ridge show the Lyell Shear stepped across a short distance to the west, (Fig. 3,  $1\frac{1}{2}$  miles east of Queenstown) by a very strong cross-cutting NW shear (the South Owen fault zone).

The Great Lyell shaft is in Lyell Schists occupying the structural position of the base of the Owen Conglomerate, in the steep upturn limb position. Here again the Bureau turned in results showing an encouraging electro-magnetic anomaly some 2000 feet in length. This anomaly awaits drilling.

#### The Schist-Corridor Area

(North-west from the Crown Lyell Quarry)

It has been mentioned before that an examination of the North Lyell level plans indicated that an echelon orebody could be expected to occur north of the old Eastern Orebody. Its outcrop would be concealed by detritus from the North Lyell fault scarp and there would be no underground workings near its position at depth. Any expected ore here would be of the low grade chalcopryite type in planes of schistosity and occurring in schist along strike of the Middle Owen upturned beds.

Movement of the Lyell Shear by the very strong North Lyell fault was some 3500 feet westwards, with the south block down some 800 feet. Such intense movement caused a high degree of rock deformation, (as encountered in the North Lyell Mine). Once again the Bureau was called upon to verify previous geophysical work (Equipotential Method) by up-to-date Turam and Self Potention methods. Again a very strong anomaly, 2000 feet in length, was outlined along the North Lyell fault zone.

A current drilling programme is intersecting new chalcopryite and pyrite ore in a grey quartzite lode along this anomaly.

#### Comstock

A fourth area selected on structural grounds for work by the Bureau geophysicists is at Comstock. The area is covered by Pleistocene glacial till but contains some known dense sulphides of lead, zinc, copper and iron. It is situated where the E-W Comstock fault intersects the Lyell Shear in the zone where the Middle Owen beds, standing vertically in the steep upturn limb position, are passing along strike into sheared volcanic and



greywacke type sediments. The Comstock copper orebodies are some 800 feet to the north west. In this case a wide anomaly, 1500 feet in length, was recorded. It has been provisionally interpreted as due to deep seated mineralisation.

In all four cases cited, strong geophysical anomalies have been recorded, due to sulphide mineralisation at places where good structural control for ore was known to occur, and where little or nothing was known about sub-surface mineralisation.

### Geology of the Individual Mines

A description of the individual mines at Mount Lyell is now given to illustrate size, grade and nature of ore as affected by the various structural controls.

#### Bornite-Chalcopyrite Orebodies

##### North Lyell Mine

##### Grade, Production and Reserves

North Lyell ore averaged 5.4% Cu. and the mine produced 200 tons of copper per vertical foot (c.f. the Mt. Lyell Mine 120 tons, and West Lyell 700 tons per vertical foot).

Between 1903 and 1953 the mine produced 4,642,860 tons of ore assaying 5.4% Cu., 1.12 ozs. Ag. per ton, and 0.013 ozs. Au. per ton.

The mine ceased production in 1953 and published reserves are 3000 tons of 3.6% Cu. ore underground, and 2,500,000 tons of 0.8% ore available for open cutting.

##### Geology

At outcrop the ore is in a schist corridor, 1200 feet wide, and about midway between the conglomerate masses of Mount Lyell and the Tharsis Ridge. At depth the ore impinges onto, and at places is actually in, hard conglomerate. The general control is provided by the intersection of the Lyell Shear and the North Lyell Fault, resulting in intense brecciation, silicification and mineralisation.

A notable feature of the North Lyell mine is the presence of large masses of buff-coloured chert veined by hematite. Mr. Hudspeth, Mine Superintendent for the Mt. Lyell Company, states that the buff chert stopes were entirely chalcopyrite ones. The bornite occurred in three different environments, viz. :

- (a) Grey quartzite containing appreciable quantities of pyrite and little or no chalcopyrite.
- (b) White or grey schists with little or no pyrite.
- (c) In the conglomerate as solid bornite with no visible gangue and no chalcopyrite.

At depth the orebodies lie flatly, controlled by the attitude of the original bedding, but pass vertically up through the fold axis until they become small vertical pipes in the steeply upturned beds (see Fig. 11(a)). Ore occurs in the upturned and replaced Middle Owen Conglomerates occupying the vertical limb of the Razorback fold immediately south of the North Lyell fault zone.

The ore was mainly bornite in a siliceous gangue, with chalcopyrite, pyrite, galena, hematite, and barite. A typical analysis is given in Table 3. The gold and silver values were below those at the Blow, but higher than in the orebodies away from the schist conglomerate contact. Some of the stopes were phenomenally rich in bornite, having many thousands of tons of ore averaging over 30% Cu. Some of the rich bornite ore has recently been found to be weakly radio-active due to the presence of a small amount of uranium (uranium mineral not determined). The vertical extent of the various ore-shoots was very variable. At depth they merged to form a large irregular orebody and then separated out again in the bottom of the mine.

Fig. 11(a) shows the North Lyell orebodies in schist totally enclosed in Middle Owen Conglomerate, but the picture is

incomplete, due to lack of information at depth. There must have been some channel for upward passage of copper bearing solutions along the North Lyell fault zone.

### Chalcopyrite-Pyrite Orebodies

#### The Mt. Lyell Mine or the Blow

##### Grade, Production and Reserves

The first one and a half million tons of ore extracted from the Blow averaged 2.85% Cu., 2.67 ounces of silver, and 0.095 ounces of gold per ton, but the grade declined with depth. After amalgamation with North Lyell in 1903 the ore averaged less than 1% Cu. and ore now in reserve in the bottom of the mine averages only 0.5% Cu.

Official production figures are :

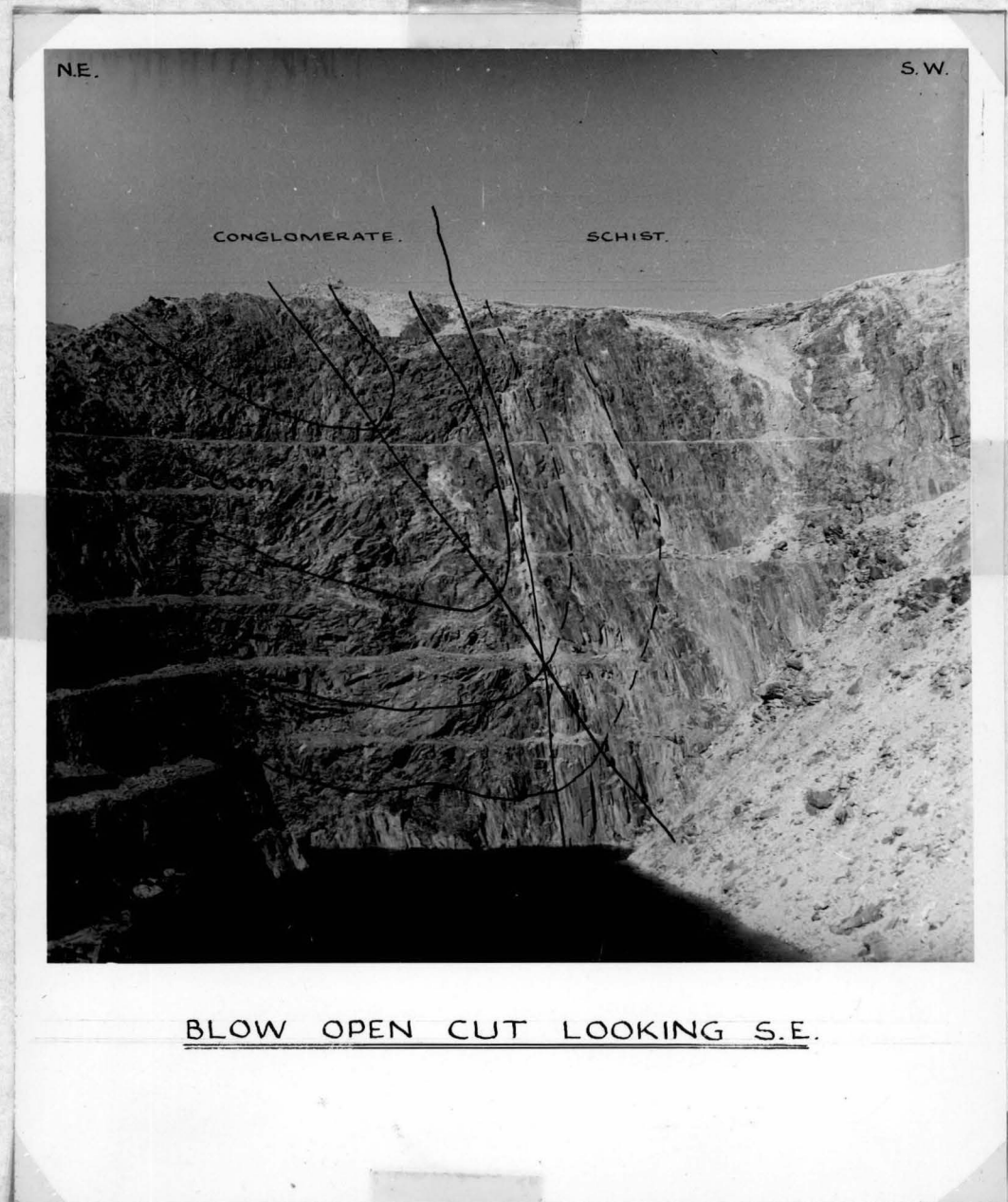
1. 1888-89: 1875 tons of ore yielding 1670 ozs. of gold, 852 ozs. of silver together worth £6,159.
2. 1896-1929: 5,497,468 tons of ore averaging 1.28% Cu., 2.0 ozs. of silver per ton, and 0.065 ounces of gold per ton.

Ore reserves were last quoted in 1924 as 1,642,122 tons assaying 0.5% Cu., 1.5 ozs. Ag. per ton, and 0.04 ozs. Au. per ton. In the following five years, until the mine closed in 1929, only 17,000 tons of this reserve were mined.

##### Geology

The Blow occupies a similar structural and stratigraphic position to the North Lyell orebodies. The ore occurs in schist occupying the position of the Middle Owen Conglomerate in the vertical limb of the Razorback upturn. The orebody lies between the crushed zones of the Gormanston and Owen Spur faults, the schist penetration along the Owen Spur fault at Gormanston being similar to that at North Lyell. The steep,

sharp contact seen on the southern wall of the Blow open cut may well represent a west dipping fault of the upturned limb. (See photo). The orebody was roughly elliptical and reached



BLOW OPEN CUT LOOKING S.E.

a maximum on No. 4 level where it was 660 feet in length and 270 feet in width; it was worked to a depth of 800 feet. In cross section (see Fig. 11), it was shaped like a banana, the upper richer portion being nearly vertical and the lower, poorer

portion lying flatly down the west dipping asymmetrical synclinal fold axis. There is little doubt that the marked fall-off in grade was related to this change in attitude. The orebody strikes NW and the dip is vertical in the upper part of the orebody but flat to the south west in the lower part.

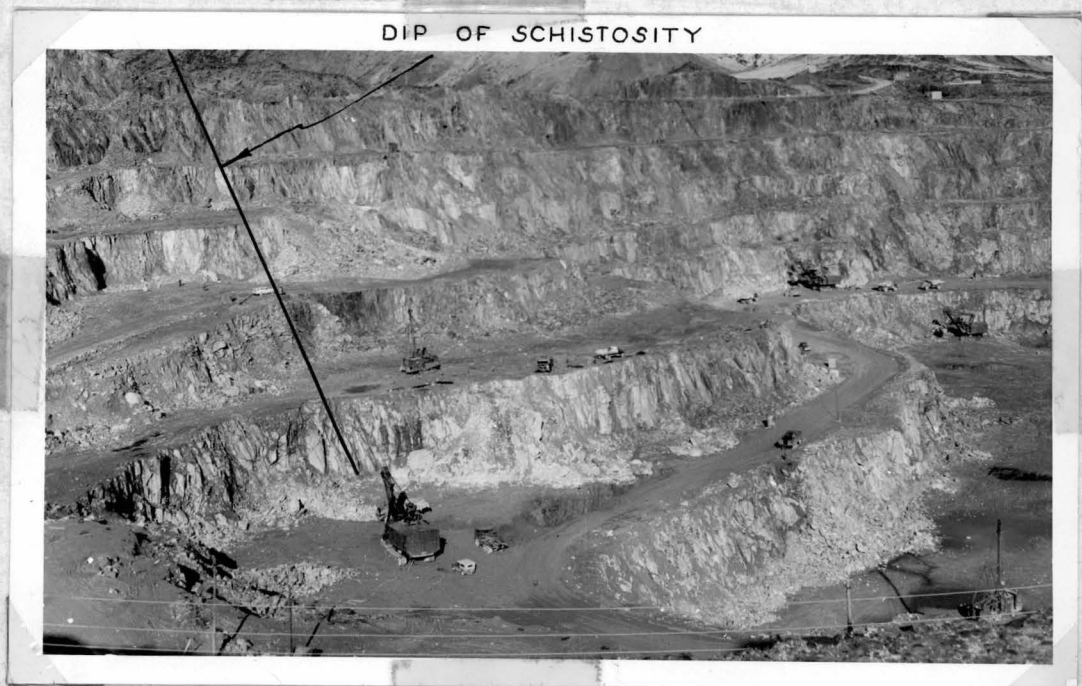
The ore consisted mainly of pyrites, averaging about 87%  $\text{FeS}_2$ . Nye et alia (12) reported that chalcopyrite was the most important copper mineral but that enargite, tetrahedrite, bornite, and chalcocite were also present as well as some galena and sphalerite. Gangue consisted of a little quartz, barite and unreplaced schist; a typical analysis is given in Table 3. (p.49). Throughout the orebody, copper values ranged from 0.5 to 6% with a tendency for the higher values to lie on the footwall. Of a number of small rich shoots within the orebody, the most important was the Mt. Lyell bonanza, cut on No. 4 level near the footwall. This shoot yielded 840 tons of ore assaying 21.03% Cu. and 1,023 ozs. of silver per ton and produced a profit of £106,312 at prices ruling in 1895. It consisted of stromeyerite with bornite, chalcopyrite, and gold in a quartz matrix (Pettersd, (16)).

#### West Lyell Mine

The West Lyell group of mines, at one time regarded as too low grade for exploitation, has now become the main producer of copper in the field, containing as much copper as the whole of the rest of the field combined. The group includes the Royal Tharsis, West Lyell Nos. 1, 2 and 3 and the Prince Lyell orebodies, besides numerous small rich zones. Around all these orebodies are low grade "halos" which in some cases merge into each other to form a large low grade disseminated copper deposit capable of being mined in a single open cut, the greatest dimensions of which will be 3600 feet in length, 1800 feet in width, and 800 feet in depth. The open cut has been so designed that a total of 105 million tons of material will eventually be removed, 66 million tons of which constitute ore, and 39 million tons waste; the ratio of ore to waste is thus



1 : 0.58, or a little less than 2 : 1.



West Lyell Open Cut Looking South

Grade, Production and Reserves

	<u>Ore</u>	<u>Grade</u>	<u>Waste</u>
Produced	25,471,486 tons	0.72%	13,814,552 tons
Reserve	40,580,000 tons	0.70%	24,862,400 tons
Total	66,051,486 tons		38,676,952 tons
Total Material	104,718,438 tons		

Geology

The West Lyell orebodies consist of a series of lenses averaging 1.0 to 1.5% Cu. in quartz sericite schist and quartz sericite chlorite schist. Some of the schist is fine-grained, dark and very chloritic, some is coarsely nodular and rich in quartz and sericite and all gradations between these extremes occur. Within any single richer ore-shoot strips of lower grade ore are strung out along schistosity. Copper occurs mainly as chalcopyrite, with occasional covellite and rarely chalcocite; gold and silver values are low but significant.

All the orebodies including the top of the Royal Tharsis are included in the one open cut in which the average grade of ore is 0.7% Cu. with the waste varying from approximately 0.1 to 0.3% Cu. The pyrite content at West Lyell averages about 9.5%. Tables 3 and 4 show the metallic and non-metallic elements present at West Lyell. The Prince Lyell has proved to be the largest orebody in the field and its downward extension is still not outlined.

The ore control has already been discussed in detail; it may be summarised briefly as follows:

Ore at West Lyell occurs as an en echelon group of lenses in schists derived from Dundas Group beds with possibly also Jukes Conglomerate. The attitude of the ore lenses is controlled by schistosity and the lenses echelon to the south west, influenced by the under-lying, competent conglomerate beds. The ore occurs in the steep, upturned limb of the Razorback fold, the fold being displaced westwards by the Razorback fault. Strong E-W faulting, related to the Linda Disturbance is an additional ore control. The West Lyell ore is regarded as low grade copper which has escaped from a deeper trap-like structure, itself the result of structural and stratigraphical influences.

Smaller chalcopyrite-pyrite orebodies which have made a significant contribution to production at Mount Lyell are the Crown Lyell, the Royal Tharsis, the Lyell Tharsis and the Lyell Comstock.

#### Crown Lyell

The Crown Lyell orebody was relatively small, varying in length from 150 to 290 feet, and in width from 30 to 70 feet though there is a considerable halo of 1% copper ore unmined.

Very little ore was produced prior to 1931 but between 1931 and 1955 when the mine closed, 436,000 tons of ore were produced assaying 1.65% Cu.; 0.259 ozs. Ag. per ton and 0.014 ozs. Au. per ton. The orebody was mined down to No. 6 level, at which level it decreased considerably in size. There is

evidence of a new unprospected echelon of ore in the Crown Shaft between the 400 and 600 ft. levels.

The Crown ore occurs in schist, replacing the ore horizon of the Middle Owen Conglomerate and is on the steep west limb of the Razorback fold, adjacent to the North Lyell fault zone. It also conforms to the attitude of the schistosity.

#### Royal Tharsis

The Royal Tharsis and South Tharsis mines were worked in separate leases in the early days of the field though they are one and the same orebody. The main production came from the mine after 1930 following the driving of the North Lyell Tunnel nearby, in 1927. Ore was mined more or less continuously from 1937 to 1954 when the mine was closed down. This was the last of the underground mines to close and marked the end of 63 years of continuous underground work at Mount Lyell.

Total production from this orebody between 1900 and 1954 was 1,578,368 tons, assaying 1.58% copper, 0.017 ounces of silver, and 0.022 ounces of gold.

The reserves about R.L. 700 ft. are given as 954,000 tons of 1.6% Cu.

The Royal Tharsis is a member of the West Lyell group of orebodies which extend en echelon to the south west from the Tharsis Ridge, and are separated by low grade zones. The Royal Tharsis ore occurs in a sericitic quartz schist with pyrite and chalcopyrite. Of all the West Lyell orebodies it is the closest to conglomerate, being within 100 feet of the conglomerate on the Tharsis Ridge and separated from sediments by schist carrying low copper values. The orebody is elongated along schistosity and reaches a maximum of 550 feet in length and a width of up to 100 feet. A deep diamond drill hole passes from the footwall into conglomerate at sea-level, 750 feet below the deepest workings and 1800 feet down dip from the outcrop. The grade improves steadily with depth. The orebody dips SW at 65° and has a 90° pitch.



### Lyell Tharsis

This was one of the four early mines to be worked profitably, and from 1899 to 1901, a total of 60,167 tons of siliceous ore was sold averaging 4.64% Cu. and containing 36,660 ounces of silver. In the following years its grade declined and open-cutting of a low grade halo surrounding it commenced.

Total production to 1956 was 759,800 tons of 1.48% Cu. ore and the reserves available by open cutting are 800,000 tons of 1% Cu. with an overburden of 387,873 tons, a ratio of ore to waste of 2.1 : 1.

The Lyell Tharsis orebody is in an environment similar to that at North Lyell, except that it is somewhat south of the North Lyell fault and is associated with strong WNW faulting. The ore (predominantly chalcopyrite and carrying some bornite and galena) is in schist, separated from conglomerate by a thin strip of hematitic schist and it occurs in the steep upturned west limb of the Razorback fold in the Middle Owen horizon. The schist does not extend far down the steep limb and mineralisation cuts out only 400 feet below outcrop. The strike follows NW schistosity and the dip is vertical.

### The Comstock Mines

The Comstock group of orebodies is situated in the Comstock Valley, on the northern side of Mount Lyell, about one mile north of the North Lyell Mine.

The orebodies at Comstock, as at Lyell, occur in Lyell Schists near the contact of schist and conglomerate. They are located on the intersection of the Lyell Shear upturn (Fig. 17) and the E-W Comstock fault (Fig. 6) and the degree of brecciation and the grade of ore is second only to that at North Lyell. Like North Lyell, the ore is associated with the development of massive chert bodies veined by hematite.

The Middle Owen Conglomerate passes along strike into altered Dundas type sediments now converted to schist and containing

the Comstock orebodies. Four separate orebodies have been located and their arrangement in section is roughly en echelon, although individual orebodies connect at certain levels.

Edwards (6) noted that the upper two orebodies have the shape, in plan, of two opposed "V's" related to the two local cleavage directions, and that both orebodies dip to the north west at 60° and pitch to the south west at 60° and 78°. They attain a maximum length of 270 feet and a maximum width of 70 feet.

Of four ore-shoots, the first and second are worked out, the third is only partially mined and on the fourth, which echelons in at depth, mining had scarcely begun when the mine was closed. The first echelon was shallow. The second echelon was mined from surface (R.L.1650) down to its lower limit at R.L.1300; the third echelon persists from outcrop at R.L.1750 to below No. 11 level (at least) at R.L.700 and lies to the west of the first orebody; the fourth echelon had its summit at R.L.1200 and it also persists below No. 11 level.

Ore consists of disseminated chalcopryite in schist with some bornite in the first and fourth echelons. Pyrite is present and Edwards (6) records magnetite, galena, copper carbonate and free gold. Aluminium phosphate has also been found at Comstock.

#### The Tasman and Crown Lyell Extended

This mine lies immediately east of the Lyell Comstock mine and in it two orebodies have been worked to a shallow depth from three levels. The orebodies are approximately 200 ft. apart, one containing patchy bornite in schist and brecciated quartzite, and the other a small but rich lode containing lead, zinc, and silver. The average metal values for the latter ore are given as :

Lead: 28.0%; Zinc: 20.0%; Copper: 0.5%; Silver: 16.00 ozs. per ton; Gold: 0.01 ozs. per ton.

The Tasman and Crown workings are in schist along the strike of steeply upturned Upper Owen Conglomerate, on the E-W Comstock fault.

### The Copper Clays

Copper clay deposits occur in valleys on the eastern slopes of the Lyell-Owen divide. It is fairly obvious that the same clays have been stripped off the ridges by erosion. The three main deposits are, from North to South, the Blocks, the Lyell Consols, and the King Lyell (Fig. 10). The three deposits are all in fossiliferous black shales of the Gordon formation which have been altered by hydrothermal solutions to ferruginous red clays, carrying native copper and exceedingly fine galena. They occur in zones of strong cross faulting relating to the Linda Disturbance and where the Middle Owen Chocolate Sandstone beds have been thinned considerably by the Haulage Unconformity. Immediately beneath the altered Gordon shales, notably where the copper clays have been removed by sluicing operations, the topmost beds of the Upper Owen, particularly grey quartzites, are hydrothermally altered and partially converted to quartz-sericite-schist and white greasy sericite.

An interesting feature of the copper clay outcrops is that native copper is forming, at present time, particularly after rain, by adsorption on the clay.

The occurrence of hydrothermal alteration and copper mineralisation as high in the stratigraphical column as the top of the Upper Owen and in the Gordon is explained structurally by the thinning of the sequence by erosion of the Chocolate Sandstone during Haulage uplift, and by strong cross faulting. One wonders what would be found at depth beneath these clays, where the stratigraphically favourable Middle Owen Conglomerate horizon occurs.

The deposits are only partially exploited and although a considerable tonnage of material is indicated, no reliable estimate of tonnage and grade is known. Difficulties in mining and treatment have hindered exploitation to date.

At the Blocks Mine the clays were first concentrated in 1904 and 15,000 tons of ore had been won by 1907 when the rich

workings above tunnel level caved in. The ore appears to have averaged 2-3% Cu.

The Lyell Consols Mine was open only for two years, 1909 and 1910, and the orebody then was described as being 400 ft. in length and containing over 94,000 tons of 3% Cu. ore.

The King Lyell clays were worked to a very shallow depth and a thin layer of clay was sluiced on the southern slope of Pioneer Spur.

Boreholes show that the ferruginous native copper clays are surrounded either by unaltered black shales and limestone, quartz sericite schist, or kaolinised sandstone. The grade of the clay ore is between 1% and 2% Cu.

#### Pyrite Orebodies

Several fairly large pyritic lenses occur in the Lyell area; they contain little or no copper and at present are not of economic significance. They have been outlined by electromagnetic surveys and field mapping, and a number have been drilled. They are similar orebodies to those at West Lyell but contain insufficient copper for exploitation. They are elongated along schistosity and contain large tonnages of ore assaying as high as 60% FeS<sub>2</sub>. All occur within Nye's en echelon zones of pyritic mineralisation.

The only pyrite orebody that has been mined is the South Lyell orebody, an echelon of the Blow orebody. This lies about 800 ft. south west of the Mt. Lyell Mine and was worked in order to assist in smelting the siliceous North Lyell ore and for export to acid works. It was discovered at a depth of approximately 500 ft. and stoping continued down about 400 ft.; it attained its maximum development of 540 ft. in length and 90 ft. in width on the No. 8 level of the Mt. Lyell Mine.

The South Lyell Mine produced 325,830 tons of highly pyritic ore and reserves are 294,000 tons of ore high in sulphur. The orebody appears to go to considerable depth.

## HYDROTHERMAL ALTERATION AND METALLISATION

Problems relating to the origin of the Lyell Schists and to hydrothermal alteration and mineralisation in the Lyell area have been the subject of special attention in a separate thesis by Solomon (21). It is proposed now to refer briefly to the schists and to hydrothermal alteration and metallisation where these features are closely associated with the orebodies and the structural control thereof.

The development of the Lyell Schists and the processes of hydrothermal alteration and metallisation are all closely related to and controlled by the deep seated Lyell Shear.

### The Lyell Schists

The Lyell Schists are mainly confined to a narrow zone near the Lyell Shear.

A rough classification into three types of schist can be made at Lyell. These are:

1. Quartz-sericite-schist
2. Quartz-chlorite-schist
3. Quartz-sericite-chlorite schist

All three types of schist are host rocks for ore, though generally the sericitic types are more strongly developed within the orebodies. Solomon (21) has shown how the extremely pyrite-rich schists are usually very sericitic, and this is in line with Schwartz's (18) findings in the Copper Porphyries of the North American Continent, and also is in line with findings of other authors, e.g. Peterson (14) who describes a quartz sericite phase as one of three hydrothermal processes in the Copper Cities Deposit; and Peterson et alia (15) describe a quartz sericite phase, with increase in silica at Castle Dome; and again Schwartz (19) recognises that the ore zone at San Manuel is marked by intense sericitisation and a minor introduction of quartz. The sericitic schists are most common adjacent to the conglomerate contact and form a quartz sericite zone, whereas the chloritic schists are of increasing

importance outside the sericite zone, away from the contact. Sericite and chlorite are the chief products of hydrothermal alteration in the ore zone. The schists associated with the rich orebodies of North Lyell, the Blow and Comstock show a development of a variable series of pale green hydrated aluminium silicates. This series represents the highest degree of hydrothermal alteration at Lyell and usually occurs either on the schist-conglomerate contact or as wall rock to some of the richer orebodies. Solomon (24) points out that considerable alteration of original sediments must have taken place to produce the hydrated aluminium silicates of the rich orebodies, involving loss of silica and addition of alumina and water in all varieties, and in some, removal or re-arrangement of alkalies. Alteration of the Owen Conglomerate calls for removal of silica (up to 30%) and introduction of alumina, alkalies and water. Though Turner (verbal discussions) considers it extremely unlikely that the highly siliceous Owen Conglomerate could be made over to quartz-sericite schist at Lyell, it is not an impossibility. At Lyell, much of the schist has been developed from a greywacke-volcanic facies sediment, but there are some schist occurrences which are extremely difficult to explain structurally, from field evidence, as representing anything else but alteration of siliceous Owen Conglomerate. In the literature, the development of an argillic phase, in the hydrothermal alteration of a wide variety of rock types, has become very well established. Schwartz (18a) notes that since 1941 a number of papers by Sales and Meyer, Lovering, Peterson, Kerr, Leroy, Schwartz and others have shown that clay minerals of hydrothermal alteration are surprisingly abundant, particularly in and near copper deposits. He also states that when later alteration attacks argillized rocks, sericite is readily formed at the expense of clay minerals. Finally he finds that quartz is generally resistant to most kinds of alteration, but it has been noted by several investigators that in cases of severe argillic alteration quartz is attacked around the periphery of large grains, and Lovering indicates that the ground-mass quartz

and orthoclase of a porphyry at Tintic is changed to clay. Under the microscope, and macroscopically, many quartz-sericite-schist specimens at Lyell have been noticed by the writer to show a streaming out of sericite flakes at the ends of strained and stretched quartz grains.

Under certain conditions of advanced hydrothermal alteration at Lyell, where ore controlling structures have provided the optimum conditions for the upward migration of hydrothermal solutions, the following system is suggested :

Siliceous Conglomerate	Argillic Phase	Quartz-sericite schist
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#### Hematization

Hematite occurs at certain places on either side of the contact zone at Lyell. It is to be seen mainly near the Blow, the north end of the Tharsis Ridge, near the North Lyell Open Cut, and at Comstock - in all cases, adjacent to the Lyell Shear. The hematization occurs only when the schists occupy the stratigraphical position of the Middle Owen. Following along strike from hematitic-schist into the unshered Middle Owen, it is found that the sediments are rich in original hematite, derived it is thought, from rejuvenation of the Dundas Ridge. The hematite has been re-worked during the process of hydrothermal alteration, and at least at North Lyell the hematitic schists are intimately associated with rich ore, lying between the orebodies and the conglomerate.

#### Silicification

Silicification is widespread in the Lyell mine area and is particularly associated with major orebodies and hence with ore-making structures, particularly the E-W fault system. Masses of siliceous breccia occur at the intersection of the Lyell Shear and the North Lyell Fault and again at the intersection of the Lyell Shear and the Comstock Fault. The phenomena of introduction or re-working of silica in the ore zone is typical of many foreign hydrothermal sulphide deposits and was referred to

frequently in the author's Reading Thesis (23), e.g. Schwartz (18) in discussing the large scale copper deposits of the North American Continent observes that, in the process of hydrothermal alteration, silica is gained in a few deposits and quartz, no doubt, is often formed by the freeing of silica during alteration. Again at San Manuel, Schwartz (19) notes that in the ore zone there is intense sericitisation and minor introduction of quartz.

Many observers of the foreign copper porphyry deposits describe a phase of hydrothermal alteration which involves a re-crystallisation of quartz with sericite and sulphide (c.f. Peterson (14) describing Castle Dome and Copper Cities). That the phenomenon is not confined to alteration of intrusive stocks is shown by Oosterbosch's (13) description of three forms of silicification invariably accompanied by sulphide intrusion at Fungurume, Katanga. Here he is describing mineralised sediments.

#### Temperature Control of Hydrothermal Alteration and Metallisation

In an unpublished report, Conolly raised the doubt that rich ore might not be found below the old mines because of the mesothermal character of the Lyell deposits, even if structures were favourable. The maximum temperature indicated at Lyell by exsolution intergrowths of bornite and chalcopyrite is  $475^{\circ}$  (Filimonova (25) and Edwards (6)), which is above that for ore of normal mesothermal origin. However, the general indication is that Lyell ore is mesothermal. Even so, this does not preclude Lyell ore from occurring at much greater depths. McKinstry (11) states that there is no consistent change in the nature of mineralisation through the explored range of more than 5000 feet in the Mother Lode, California; and he further points out that a number of other mesothermal deposits have been mined to depths of 3000 to 6000 feet.

Nevertheless, the main control for alteration and mineralisation (including metallisation at Lyell) is structural, and it has been shown that there is also a stratigraphical influence in that the orebodies are located near the same level in the geological column. Away from Mount Lyell, but still on



the Lyell Shear, this stratigraphical level is at the base of the Owen Conglomerate i.e. in Jukes Conglomerate or in Dundas beds. At Lyell, rapid thinning of the Owen sediments, facies changes, and a high degree of cross faulting and shearing, result in the formation of schists and consequent ore deposition at the base of the Owen Conglomerate, in the Middle Owen, and in extreme cases as in the copper clays, in the Gordon beds.

The final dominating influence which guided the emplacement of ore, at least in the rich North Lyell orebodies, is one of relative competency. The impermeable Owen Conglomerates have been folded into trap-like structures which have dammed back the copper bearing hydrothermal solutions, halting their relatively easy passage up through the sheared Dundas beds. In rare cases, as in some of the North Lyell stopes, bornite may be seen in all stages of replacement of Owen Conglomerate, with the final stages of solid bornite showing relict pebble outlines on fresh faces. The sulphides in this mine have overstepped the schist-conglomerate boundary in a few cases.

In dealing with the question of relative competence, a reference is pertinent here to some views expressed by Dr. Campana (verbal discussions in the field). Campana does not necessarily see the need for a recurrence of Dundas type facies during Middle Owen sedimentation. He considers that rock deformation, due to tectonic forces would allow the penetration of hydrothermal solutions into the Owen Conglomerate, converting it to schist. In other instances, as at Comstock mullock quarry, he would prefer to postulate tectonic intrusion rather than facies change. He uses the term tectonic intrusion in the sense that sheets of one rock type can be wrapped around and apparently interbedded with another rock type. The mechanism requires intense tectonic activity and rocks with very marked difference in competency (conditions which could well be fulfilled at Lyell). He recalls Alpine occurrences, which he has seen in Europe, where thin slabs of granite, no more

than a few feet in width and some miles in length are enveloped in limestone. In the Alpine case cited the highly competent granite is wrapped in incompetent limestone, whereas at Lyell the incompetent Dundas type sediments are "enclosed" by highly competent Owen Conglomerate. No doubt, however, extraordinary tectonic effects could be produced by Tabberabberan orogeny on the rock types at Lyell.

The writer agrees with Conolly that the failure of ore at depth is more likely to be attributable, at Lyell, to structural control than to hydrothermal, but disagrees with Conolly in that the author considers that the mesothermal nature of Lyell ore does not preclude it from continuing to much greater depths than at present mined.

#### SUMMARY

The processes of sedimentation and the development of ore-making structures at Lyell were controlled by north-east directed compressional forces acting against a central, resistant Precambrian massif. In the Cambrian a eugeosynclinal environment developed, into which volcanic and greywacke sediments were received from the west. This process gave way, in the Ordovician, to the accumulation of well sorted, highly siliceous sediments, shed from the Precambrian massif on the east. Finally this was followed by Tabberabberan orogeny in the mid-Devonian with ore emplacement in the late Devonian.

The very sharp contrast in conditions of sedimentation, in which basic, unsorted, and rapidly buried, volcanic and greywacke type material was overlain by thoroughly re-worked and well sorted, siliceous sandstones and conglomerates naturally enough lead to equally sharp contrasts in relative competency of the resulting rock types. Under the ensuing conditions of severe orogeny during the Tabberabberan, the volcanic and greywacke sediments of the Dundas Group sheared to form schists, whilst the sandstones and conglomerates of the Owen were folded into beautifully developed structures.

Burial of the Dundas type sediments by the Owen, interfingering of the two types of sediments during rejuvenation of the Dundas Ridge, (caused by intermittent uplift along the Lyell Shear during the Ordovician) followed by severe Tabberabberan folding and faulting and subsequent hydrothermal alteration, have all combined to produce the highly irregular schist penetration into Owen Conglomerate with its quasi-intrusive character.

The possibility has been discussed that in some cases tectonic intrusion, rather than facies changes, has led to the development of the complicated schist penetration of the Owen Conglomerate.

Thus the important stratigraphical control for ore at Lyell is the sharp contrast in relative competency of the Dundas Group and the Owen Conglomerate sediments, leading ultimately to the development of trap-like structures to receive the richer ore.

The orebodies at Lyell all occur in a longitudinal zone, some 2500 feet in width, extending from Comstock to the Blow, a distance of two and a half miles. The Lyell Shear, a strong meridional shear zone, is the dominant structure controlling ore deposition. It is expressed at Lyell as an intermittent, overturned, asymmetrical, synclinal fold, with the west limb steeply upturned and at some places overturned. Apart from the main ore-shoots of the North Lyell Mine, the orebodies at Lyell all occur in the steeply upturned west limb of this fold, and location within this limb is controlled by the cross-cutting NW and WNW faults. Within the limits of the Linda Disturbance, i.e. the actual Lyell ore zone, these cross-cutting faults are swung to an almost E-W trend. They are really asymmetrical folds with one flat limb and a steep faulted out limb. They combine to form a crude rift structure with its most deeply down-faulted centre lying between the Pioneer and Whaleback faults. At their point of contact with the Lyell Shear they are dragged round to a N-S strike with the steep limb facing west. Cross faulting has the effect of stepping the Lyell Shear westwards. To a certain degree the various Tabberabberan structures seem to have developed concurrently.

The Lyell Shear is not only the dominating structural ore control but movements on the Shear throughout the Palaeozoic also exercised a profound effect on sedimentation and this is of particular importance in connection with the deposition of the host rocks. Ore control is therefore both structural and stratigraphical, for there is also a dominating stratigraphical influence, in that the orebodies are all at, or very near to, the schist-conglomerate contact, occurring in schists occupying the stratigraphical position of the Middle Owen Conglomerate (as at North Lyell, the Blow and Comstock) or of the Jukes Conglomerate and/or the Dundas Group beds (as at West Lyell and the Royal Tharsis).

The Lyell Shear, therefore, may be regarded as the major influence which conditioned the zone structurally and stratigraphically (i.e. physically) for the reception of ore by subsequent chemical processes, the copper bearing solutions themselves gaining access to the ore positions via the Lyell Shear.

Along the entire length of the Lyell Shear, it is only in the relatively small zone of two and a half miles in length by 2500 feet in width, where the sediments have been so severely cross fractured, that the hydrothermal and ore-bearing solutions have been able to penetrate as high up the stratigraphical column as the Middle Owen Conglomerate. In the extreme case of the Copper Clays, the solutions were able to make their way to the top of the Owen Conglomerate succession and into the Gordon beds. This maximum ascent is associated with severe cross-faulting and a thinning of the Middle Owen, in the Chocolate Sandstone, at the Haulage Unconformity.

The upturning effect, on the Lyell Shear is also most noticeably developed where the Haulage Unconformity thins the Middle Owen.

Investigations into the en echelon ore-control structures have lead to the drilling of two large low grade orebodies, one beneath West Lyell and the other in the Schist-Corridor area. These marginal grade orebodies may eventually contribute an enormous tonnage to the total of Mount Lyell production.

Finally, the interpretation of structure and stratigraphy have lead to the conclusion that suitable ore-making structures can be expected to recur at depth.

### CONCLUSIONS

At Comstock the flat east limb position at the horizon of the Middle Owen has not yet been prospected. Furthermore, in the entire Lyell Mine area, the flat east limb, in the lower stratigraphical position has not been explored at all. Interpretation of mapped structures and measured stratigraphical widths, indicates that this position lies within 2000 feet of surface at West Lyell, and possibly a little deeper at the Blow and North Lyell. The prospect zone is about 1000 feet below main adit levels, a depth by no means too great for normal mining operations.

World wide experience in exploration has shown that ore is likely to occur adjacent to known large-scale ore occurrences, if ore controlling structures are repeated in that vicinity.

The geological work carried out during the past four and a half years, summarised in this thesis, does indicate very positively that structural and stratigraphic conditions, suitable for the repetition of ore do occur within minable depth, beneath the known Lyell orebodies. It is, therefore, most important that this deeper prospect zone be explored, for the prize indicated would have far reaching economic significance.

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June, 1957.

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TABLE 3

A typical analysis of Mount Lyell Mine (Blow) ore :

Iron	43.8%
Sulphur	50.0
Silica	2.6
Alumina	0.5
Barite	0.5
Copper	1.0
Lead	0.7
Zinc	0.3
Arsenic	0.33
Silver	1.50 ozs. per ton
Gold	0.04 ozs. per ton

A typical analysis of North Lyell ore in bulk :

Copper	6.15%
Silica	62.7
Iron	9.1
Alumina	7.5
Barite	1.5
Sulphur	Not determined
Silver	1.3 ozs. per ton
Gold	0.015 ozs. per ton

A recent spectrographic analysis carried out by the Electrolytic Zinc Company at Risdon showed the following metals present in quantities of approximately 0.01% :

<u>North Lyell:</u>	Co., Mo., Mn., and Sb.
<u>The Blow:</u>	Ni., Mo., Mn., and Sb.
<u>West Lyell:</u>	Ni., Mn., and Sb.

TABLE 4

Electrolytic Refinery Slimes

Typical Bulk Assay

Copper	76.549%	(by difference)
Lead	1.8	
Iron	0.11	
Nickel	0.034	
Zinc	Tr.	
Cobalt	Tr.	
Silver	1.62	(508.81 ozs. per ton)
Gold	0.26	(81.005 ozs. per ton)
Insoluble	1.2	
CaO	0.057	
Selenium	2.1	
Tellurium	0.17	
Arsenic	0.06	
Antimony	0.13	
Bismuth	Tr.	
Moisture	7.51	
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	100.000	
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The copper content of the slimes varies from 72% to 78% approximately.



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